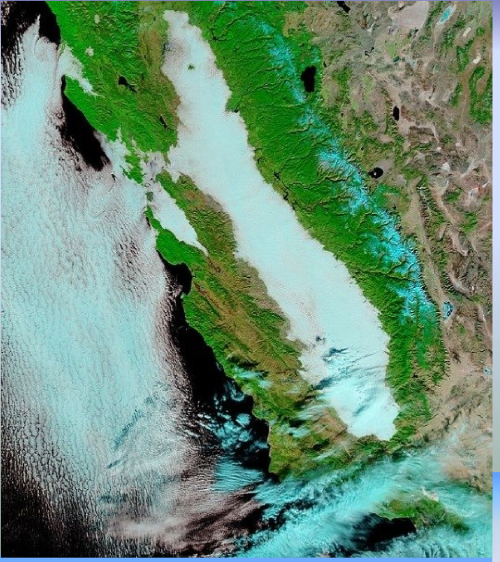

Thirty Years of Cloud Cover Patterns from Satellite Data: Fog in California's Central Valley and Coast

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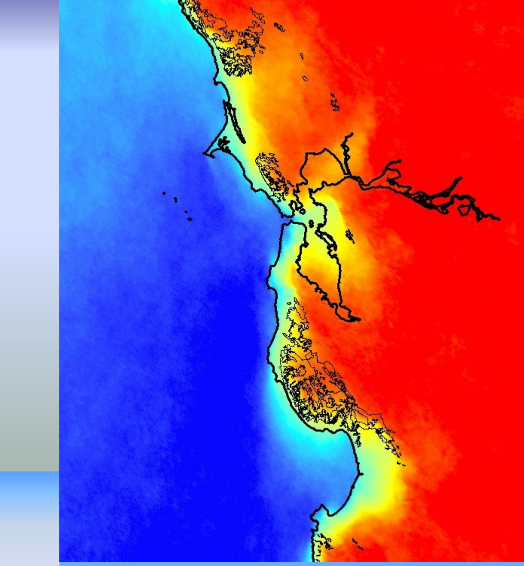

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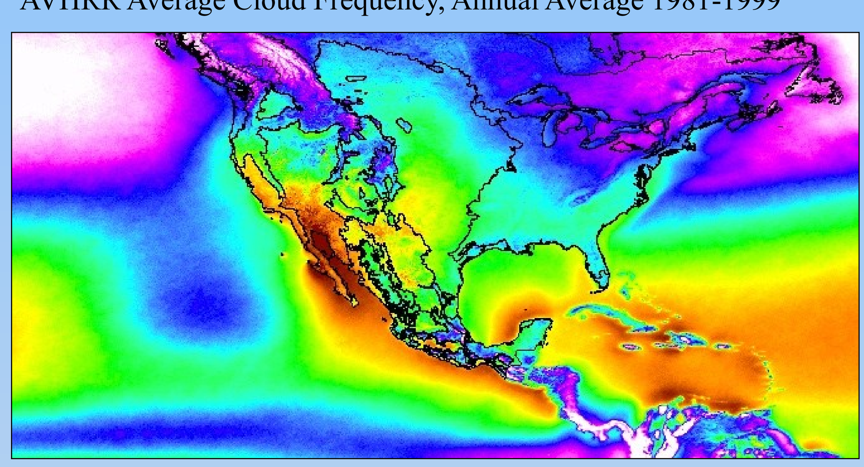
Can satellite imagery be used to determine multi-decadal trends in California's summer coastal and winter Central Valley fog?

Introduction

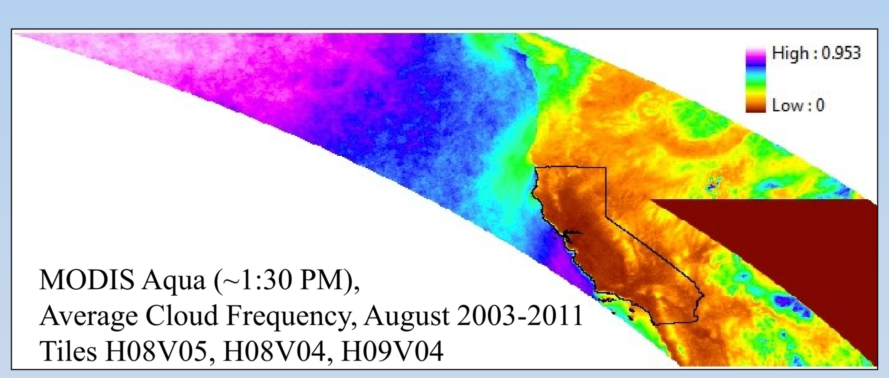
In an effort to assess long term trends in winter fog in the Central Valley of California, custom maps of daily cloud cover from an approximately 30 year record of AVHRR (1981-1999) and MODIS (2000-2012) satellite data were generated from data stored on the NASA Earth Exchange (NEX). Spatial rules were then used to differentiate between fog and general cloud cover. Differences among the sensors (e.g., spectral content, spatial resolution, overpass time) present problems of consistency in cloud classification, but the results may be sufficiently accurate to suggest real long term trends. The frequency and extent of Central Valley winter ("Tule") fog appear to be on the decline, especially in the months of November, December, and February. These results may have strong implications for growers of fruit and nut trees in the Central Valley dependent on winter chill hours that are augmented by the foggy daytime conditions.. The generation of cloud frequency products for California and beyond allows similar analyses for other areas of concern, such as the coastal fog belt of California. However, the relatively coarse spatial resolution of the AVHRR LTDR (Long Term Data Record) data (~5-km) may be limiting for fine-scale analysis of trends.

AVHRR Average Cloud Frequency, Annual Average 1981-1999

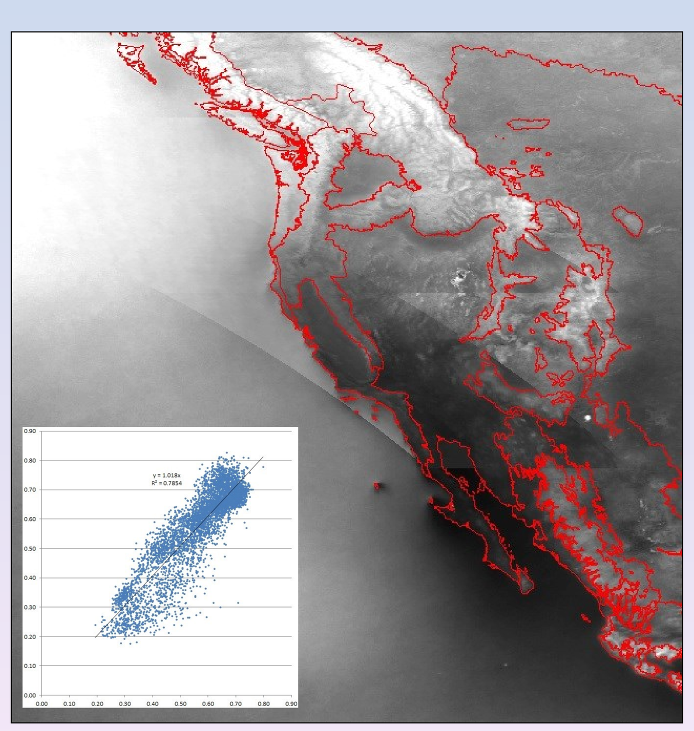


AVHRR data are collected at a nominal spatial resolution of 1.1 km, but long-term data have been processed and stored at .05 degree (~5 km), as part of the Long Term Data Record (LTDR) product. Custom classification of cloud cover on these daily images allows the generation of cloud climatology products such as the one at left.

MODIS Terra and Aqua (with overpass times of ~10:30 AM and ~1:30 PM, respectively) daily reflectance data at ~500 meter resolution were also classified to daily cloud cover for 3 sinusoidal grid tiles, displayed here in geographic projection.



MODIS Aqua (~1:30 PM), Average Cloud Frequency, August 2003-2011 Tiles H08V05, H08V04, H09V04

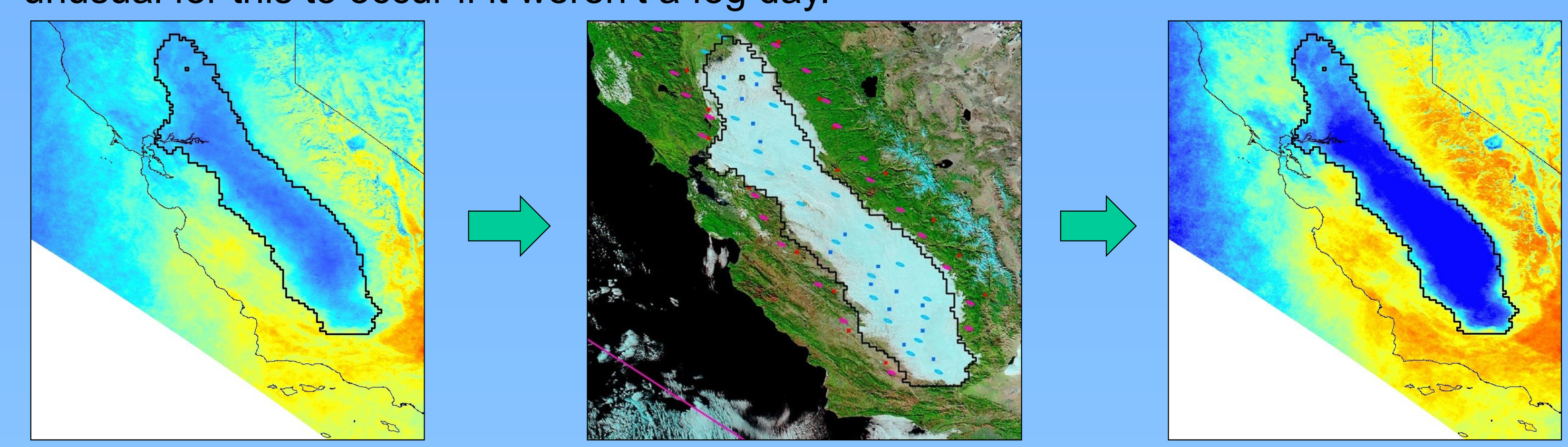


AVHRR MODIS Classification Comparison

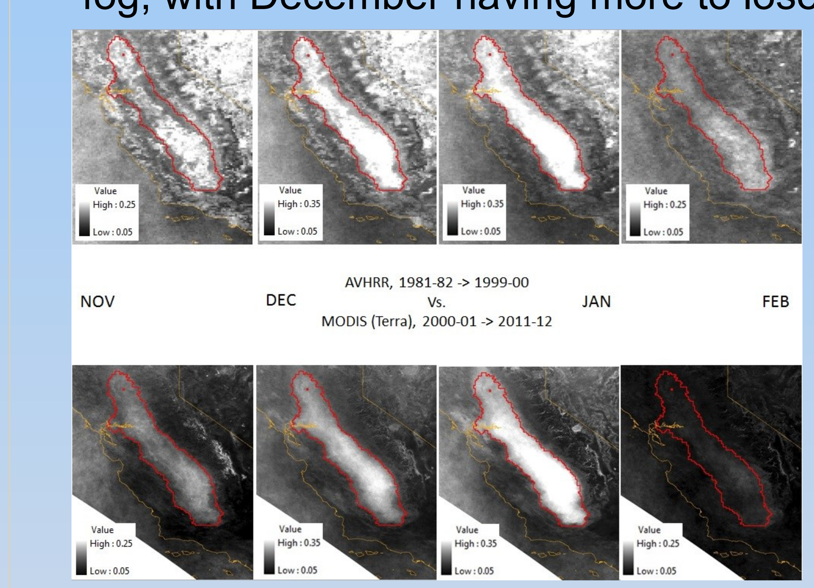
Overlay of annual cloud frequency for three MODIS tiles over the AVHRR version (note diagonal bands associated with the edges of MODIS tiles) demonstrates the reasonably close match between the products, with correlations around 0.9 and little systematic difference. (Much of the difference could be due to real change.) This suggests that the two products might be reasonably compared for assessment of relatively long-term spatio-temporal trends.

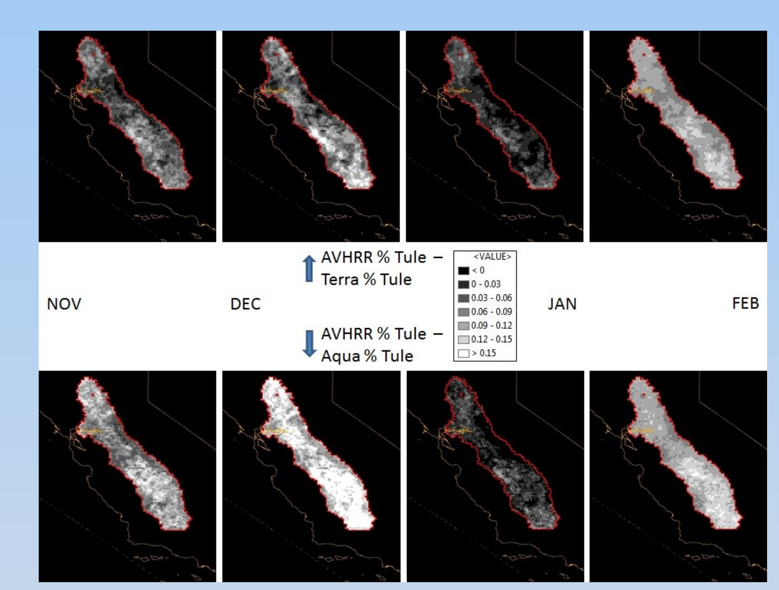
California Central Valley Winter Tule Fog Classification: AVHRR and MODIS

Monthly cloud frequencies for both AVHRR and MODIS were converted to Central Valley Tule Fog frequencies with the use of a simple daily spatial rule: if the number of points classified as cloud within the Central Valley (blue points, circles) on a given image exceeded the number of points classified as cloud on the periphery of the valley (red points, circles), all cloud cover on that image was considered fog. It would be unusual for this to occur if it weren't a fog day.

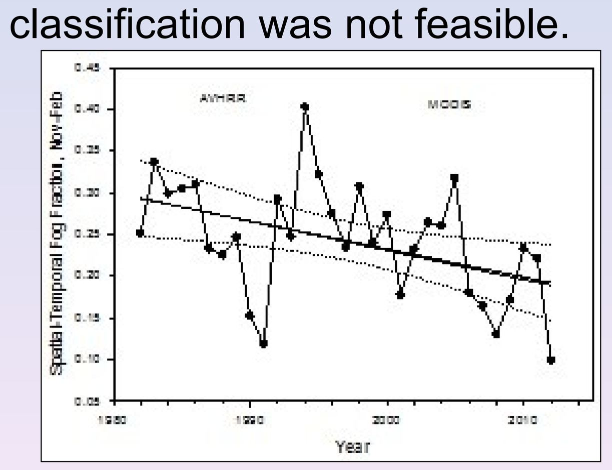


As seen in the resulting monthly valley fog frequencies below, both sensors show the strong Central Valley Tule Fog pattern, with a mid-winter peak. But the 1981-1999 AVHRR generally shows more fog than the 2000-2012 MODIS. The AVHRR classification may have more error (speckle likely a land-cover related bias in cloud classification), but it is also flown later in the day when we would expect less Tule Fog. A comparison with MODIS Aqua (~1:30 PM overpass) may therefore be more appropriate. The differences between AVHRR and MODIS are even more striking with comparisons to Aqua (subtraction images below right), especially in months other than January, particularly for December. This fits a model of "shoulder months" losing more fog, with December having more to lose.

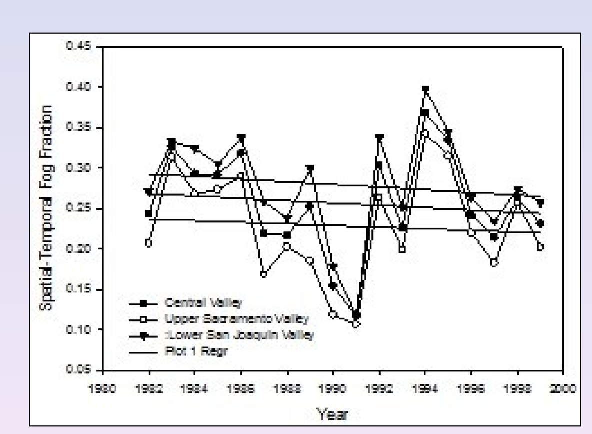




Plotting the total fog amounts for the entire Central Valley across the entire time period (below left, 1981-82 winter to 2011-12) shows what looks like a significant downward trend. However, much of this change over time could be explained by differences in processing between the two sensors. For example, just focusing on AVHRR values in the below right figure shows very little trend through 1999, regardless of the portion of the Central Valley. Unfortunately, AVHRR data after 1999 are not part of the Long Term Data Record (LTDR) used in this study, so direct comparison of AVHRR and MODIS cloud classification was not feasible.

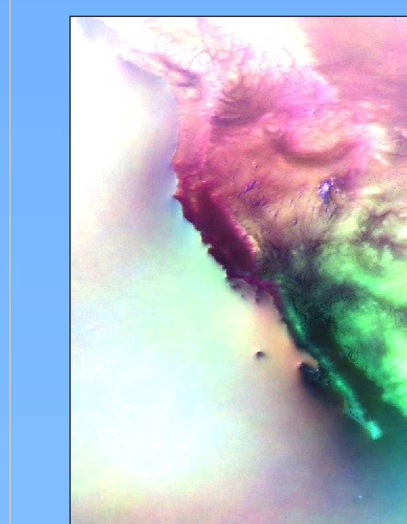


Trend across sensors…



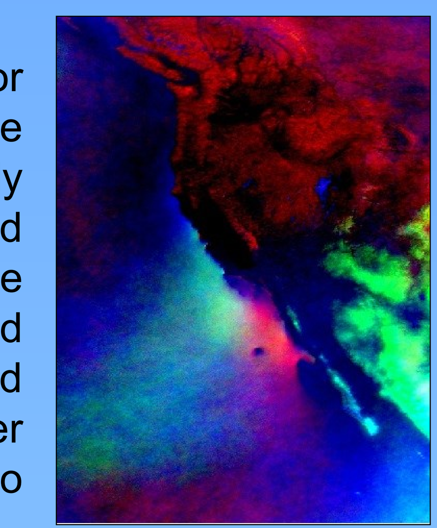
But… no obvious trend within time of one sensor

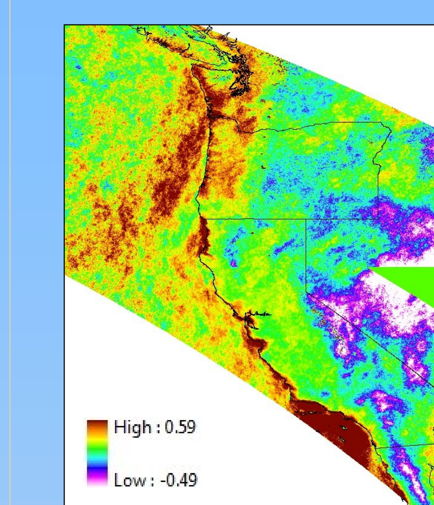
Pacific Coastal Fog: Daily and Seasonal Patterns and Multi-Decadal Trends



AVHRR: Coarse Seasonal Patterns

~2 decades of AVHRR data are useful for large area climatological products. On the left is an RGB display of May + June, July + August, and September + October cloud frequency. The right figure is the equivalent, but brightness normalized and color enhanced. Note the northward movement of relative peak cloudiness over the Pacific (from reddish to greenish to blueish) from spring through summer.



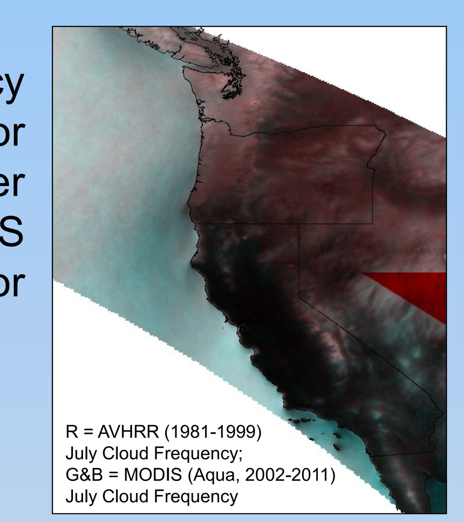


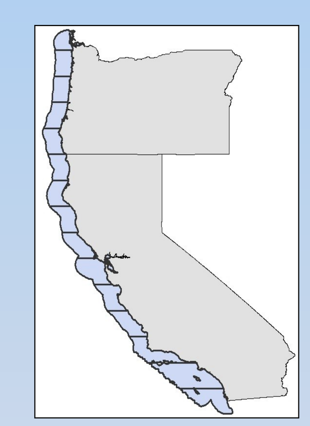
MODIS: Finer Scale Daily Variability

The higher resolution 2 overpasses per day of MODIS, on the other hand, allows a more detailed look at finer scale cloud climatology. Here, by subtracting MODIS Aqua July cloud frequency from MODIS Terra July cloud frequency, we can see a climatological representation of average fog burnoff between ~10:30 AM and ~1:30 PM. Browns and yellows in the legend indicate higher frequencies in the morning MODIS Terra, associated with burnoff. Blue, purple, and white show the increase in cloud cover associated with monsoonal thunderstorm development. Greens indicate little difference.

Multi-sensor Overlay for Long Term Comparison

A multi-band overlay of AVHRR-derived July cloud frequency and MODIS Aqua-derived July cloud frequency creates color where the two show discrepancy: reddish hues indicate higher values in AVHRR; cyan hues indicate higher values in MODIS Aqua. Whether these are related to multi-decadal change or sensor processing differences is difficult to determine.

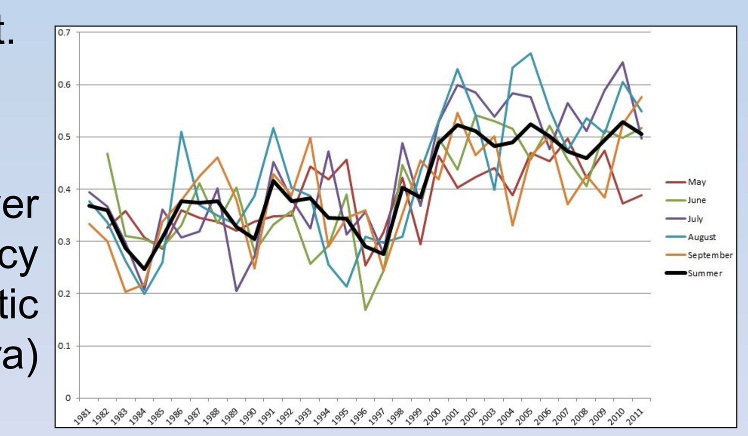




Multi-Decadal Trends in Cloud and Fog

Long term trends in fog can also be assessed with summary statistics across areas, for example, over latitudinal bands within a half degree of the coastline, as depicted on the figure at the left.

Integrating across the latitudinal bands over time shows possible trends in fog frequency within a half degree of the coast. Systematic differences between AVHRR and MODIS (Terra) are likely in this time series.



Conclusions

Broad multi-decadal trends in fog and cloud cover may be detectable with new processing of daily AVHRR and MODIS data from 1981-2012. Winter fog may be decreasing in the Central Valley and coastal fog may be increasing, but possible systematic differences in the products needs to be accounted for. Fine scale changes (such as those near the coast) may be more difficult with the coarse .05 degree resolution of the AVHRR data.

Acknowledgements:

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